This is a post-print which is published in Carbon Trends, Elsevier with DOI: 10.1016/j.cartre.2021.100131

Declining Carbon Emission/Concentration during COVID-19: A critical review on temporary relief

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Abstract

In December 2019 the deadly pandemic COVID-19 traumatized mankind through its lethal impact. To seize the outbreak, nationwide/region-based lockdown strategies were adopted by most of the COVID-19 affected countries. This in turn resulted in restricted transportation via surface, water, and air, as well as significantly reduced working hours of the industry sectors, so on and so forth. The obvious outcome was a sudden discernible decline in atmospheric adulteration. Accordingly, the anthropogenic emissions at the global and regional/local scales were examined during the lockdown period by several researchers using both or either satellite-based and ground-based monitoring. Among several other air-contaminants, carbon has a dominant toxicological profile causing adverse health effects and thereby attracting researches interest in carbon-release probing during the systematic confinement period imposed by the ruling authorities across the globe. The results of those studies indicated a confirmed decline in carbon emission/concentration making the air more breathable for the period. In this review, the studies related to anthropogenic emissions of carbon during the lockdown period are accounted for by compiling the recently reported data from published articles.

Keywords: Carbon emission/concentration; COVID-19; Carbon monoxide; Carbon dioxide; Black Carbon.

1. Introduction

Carbon emission had been perhaps pre-historically started since the discovery of fire marking the birth of civilization. An accumulation of the ever-increasing rate of carbon emission/concentrations with the tremendous collective energy demands has led mankind to be affected by its detrimental effect on the environment. Carbon emission/concentration is often stated as one of the main causes of global warming[1] and also responsible for causing human health hazards affecting cardiovascular, neurological, respiratory complications even leading to death[2]. Amongst different emission sources, the transportation sector has been identified as the major contributor on top of the industry sector in a recent report[3] based on data of the United States (Fig 1). The current COVID-19 epidemic started at Wuhan, China[4] in 2019 and spread rapidly across the globe affecting 220 countries[5]. To break the transmission chain, the lockdown was imposed in most of the affected countries around the world, which in turn restricts the vehicle movement[6,7] and forces most of the industries to remain shut down for the specified period[8,9]. Consequently, the carbon emission originated from vehicles, and the industry sector experienced a sudden reduction. Such occasional depletion in carbon emission/concentration has been reported by several researchers based on numerous studies across the globe. However, to get the complete perception of carbon emission/concentration reduction after the outbreak of the COVID-19 pandemic, the published reports are reviewed here. For the sake of categorical analysis of the reported literature, the review has been performed based on the studies over land and oceanic sub-divisions. The published results from the lands are further stratified according to the coverage area as well as the major countries of the globe.

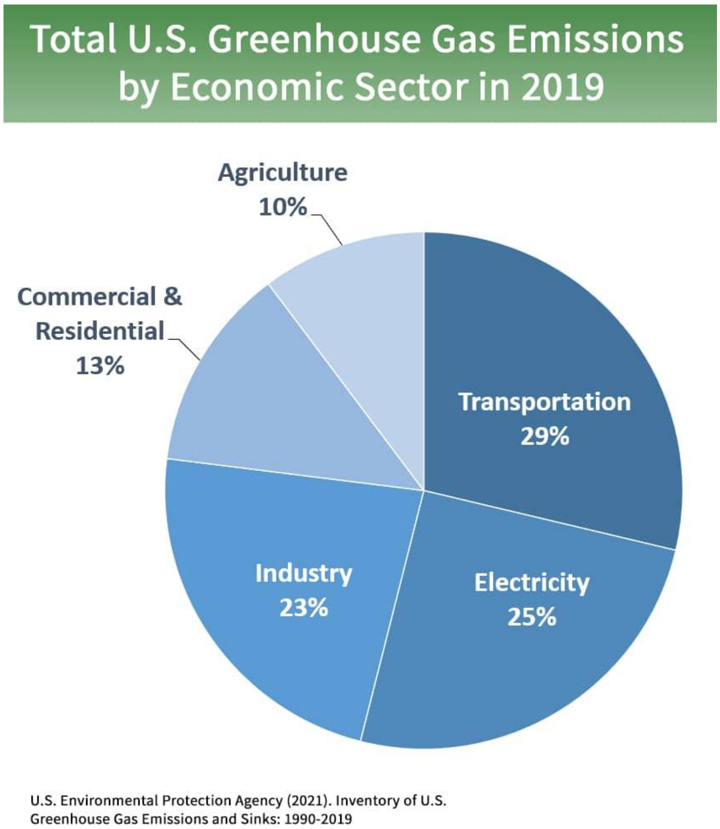

Fig 1. Sector-wise greenhouse gas emission. (Reproduced with permission from EPA, USA https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions)

2. Carbon Emission/Concentration over the Land Region

On the account of the encompassed area over the land region utilized for the study to estimate the carbon emission/concentration, the comprehensive assessment is further sub-divided as cumulative studies, i.e. collecting sample data all over the world, and then as regional studies i.e. collecting sample data from a specific country/region. Initially, the cumulative studies will be discussed and then the regional ones.

2.1 Cumulative Studies

In assessing the trend of carbon emission/concentration during the COVID-19 outbreak, several researchers around the earth followed extensive research over the substantial landmass covering several countries of different continents. Liu et al.[10,11] monitored global carbon dioxide (CO_2) emission of different countries like China, US, India, Japan, Brazil, Russia, Germany, France, Italy, Spain, etc. by collecting near-real-time data from January 1st, 2019 to June 30th, 2020. The study revealed that there is an abrupt 8.8% reduction in global CO_2 emissions in the first half of 2020 in comparison to the same period of 2019. Quéré et al.[12] also conducted a similar study and reported that daily global CO_2 emissions diminished by 17% by early April 2020 compared to the mean 2019 levels (Fig 2). Sikarwar et al.[13] assessed the global carbon emission considering US, EU-28, China, and India. They found that enforced lockdown caused a temporary reduction in anthropogenic CO_2 emission by 14%, mainly due to a concurring decrease in surface and air traffic. During the COVID-19 pandemic, the power requirements of the industry sector also declined, which in turn influenced the usual carbon emission. Bertram et al.[14] found that the COVID-19-induced economic downturn and the corresponding reduction of electricity demand along with the decrease in coal production led to a notable drop of 6.8% in CO_2 emissions across the global power sectors. Evangeliou et al[15]examined the change in black carbon (BC) emission over Europe utilizing in-situ observations from 17 European stations in a Bayesian inversion framework. They measured the BC emission during lockdowns and compared the data to the same period in the previous 5 years. They found that BC emissions declined by 23 kt with an average of 11% across Europe. Impacts on global climate due to the pandemic were estimated by Forster et al.[16] using data of 123 countries for the period January to June 2020. They also found a sharp fall in CO_2 emissions during the lockdown span.

The cumulative studies comprehensively indicate confirmed reduction in carbon emission/concentration during lockdown periods across the globe.

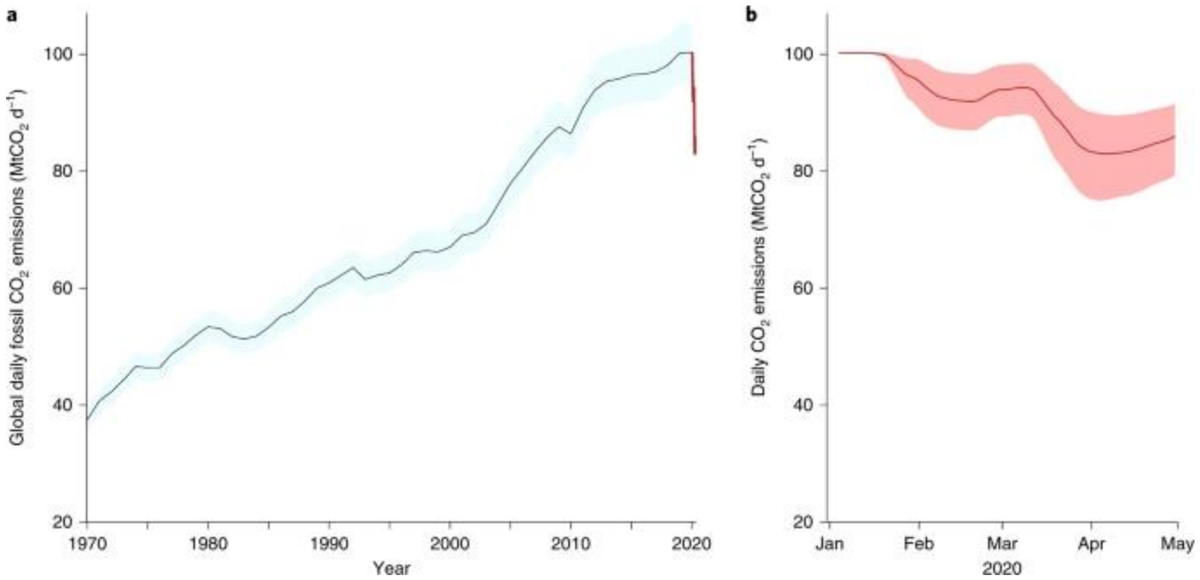

Fig 2. Global daily fossil CO_2 emissions ($MtCO_2d^{-1}$). (Reproduced with permission from Corinne Le Quéré et al., 'Temporary Reduction in Daily Global CO_2 Emissions during the COVID-19 Forced Confinement', Nature Climate Change 10, no. 7 (July 2020): 647–53, https://doi.org/10.1038/s41558-020-0797-x)

2.2 Country-based Studies

The countries around the world differ widely in terms of annual carbon emission/concentrations. According to the report[17], China, United States, and India are the top three emitters of CO_2. Moreover, the industries and the transportation sectors are found to be the major contributors (> 80%) of annual CO_2 emissions. Consequently, the effect of the enforced shutdown, to combat the COVID-19 pandemic scenario, on carbon emission/concentration are expected to be more significant in the top three countries as mentioned before. Thus the authors selected this under the purview of the present review.

2.2.1 China

Owing to the rapid economic development of the world's most populous country, China can be anticipated to experience a substantial decline in carbon emission/concentration during the shutdown session. Zhang et al.[18] examined the effect of the COVID-19 pandemic on China's transportation sector in terms of CO_2 emissions (Fig 3). They reported that the COVID-19 had a greater impact on transportation energy consumption and CO_2 emissions than SARS. Liu et al.[19] also estimated the impact of the COVID-19 outbreak on the CO_2 emission of China. They found that the reduction in CO_2 emission in the first four months of 2020 is 6.9% compared to the same period in 2019. However, in April 2020, the CO_2 emission becomes comparable to the same span of the previous year indicating rapid recovery of China's national economy. Wang et al.[20] estimated the reduction in CO_2 emission in different sectors (industrial, transport, and construction) of China. The investigation showed that net CO_2 emissions related to fossil fuel combustion reduced by 18.7% with significant contributions from industry sectors (12.2%), transportation (61.9%), and construction (23.9%). Han et al.[21] assessed the effect of COVID-19 on carbon emission based on the domestic data of China. The assessments indicate a fall of 11.0% in CO_2 emissions where ground transport made the most significant contribution (25.0%). Zheng et al.[22] monitored the alterations in anthropogenic emissions of China from January to March in 2020. They found that the CO emission was much lower in comparison to the previous year within the same span and noted that the lowest emission was recorded in February (28%) 2020. In another study[23], they have employed satellite-based data between January and April 2020 and estimated that China's CO_2 emissions reduced by 11.5% in comparison to the same period in 2019. The study of Tohjima et al.[24]reported CO_2 emission in China from February to March 2020 based on 25 years of data from a weather station located at Hateruma Island. The analysis depicted a drop of $32 \pm 12\%$ and $19 \pm 15\%$ in China's fossil-fuel-combustion-based CO_2 emissions during February and March 2020, respectively.

Zhou et al.[25]studied the change in carbon monoxide (CO) concentration in 1375 sites of China during lockdown employing surface-based and satellite-based observations. They found that the average CO surface concentration was reduced by 18.7% with a spatial variation of 8-27%. Zhang et al.[26] monitored the air quality in China during the COVID-19 pandemic covering 367 cities from 23 January 2020 to April 22, 2020. Their study revealed that CO concentration dropped by 30% due to the adopted traffic restriction to cease the spread of viral transmission. Xu et al.[27] investigated the quality of air of central China during the pandemic from January to March 2017-2020. They observed a 27.9% decrease in CO concentration in three cities, namely, Wuhan, Jingmen, and Enshi. Xu et al.[28] studied the BC concentration in the megacity Hangzhou, China, and found a 44% reduction. Bai et al.[29] examined the air quality during the lockdown in Shanghai Municipality, China in the period 25 November 2019 to 22 May 2020. They found a steady reduction in CO concentration in the city during the lockdown period. Spatiotemporal variations of air pollutants were studied by Yuan et al.[30] from January to March 2020 at megacity Hangzhou, China. Their result exhibited that CO concentration was reduced by 30% in comparison to the normal period.

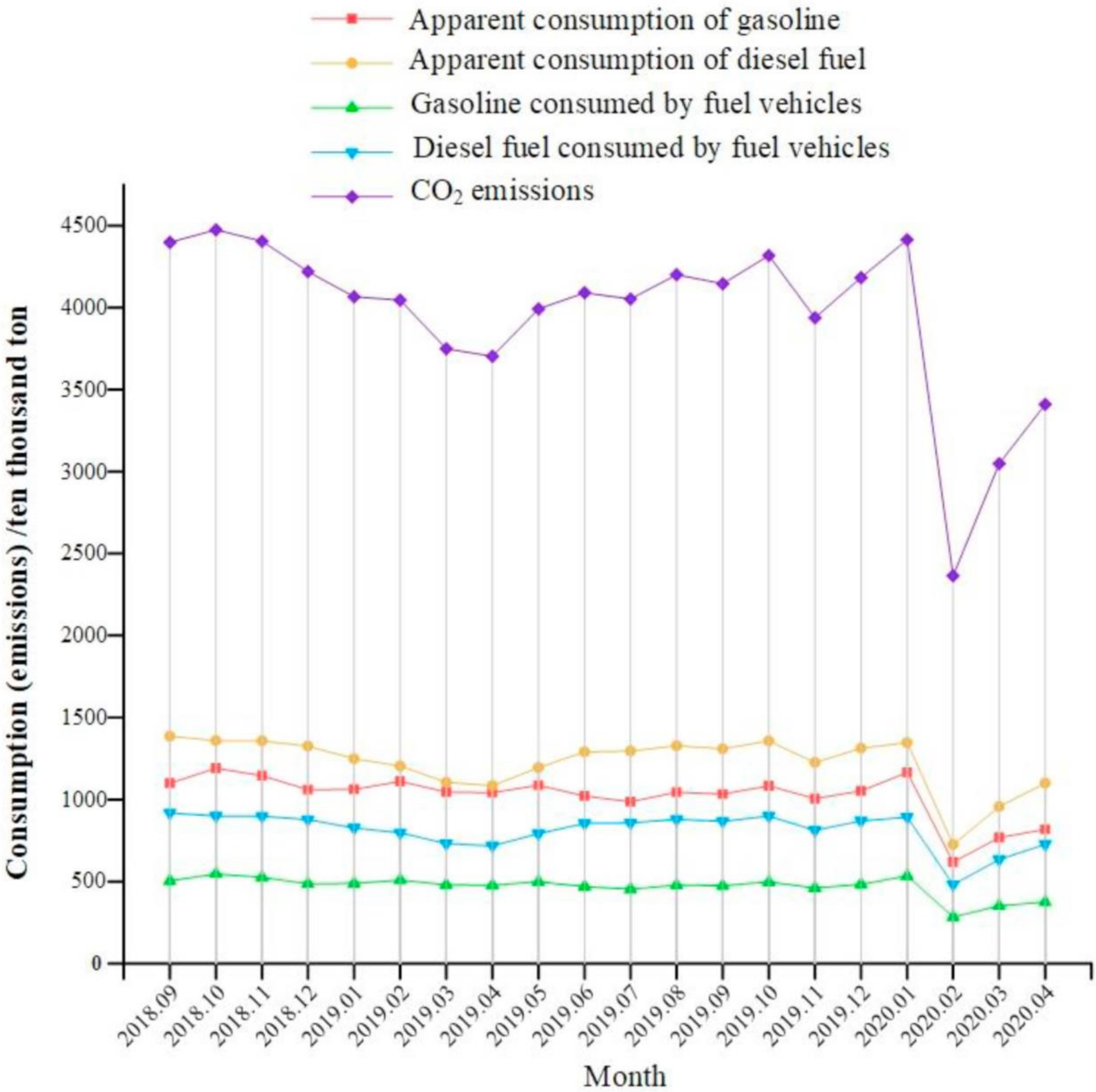

Fig 3. Variation trend of apparent consumption of fuel, fuel consumed by fuel vehicles, and CO_2 emissions from September 2018 to April 2020. (Reproduced with permission from Xinxin Zhang, Zhenlei Li, and Jingfu Wang, 'Impact of COVID-19 Pandemic on Energy Consumption and Carbon Dioxide Emissions in China's Transportation Sector', Case Studies in Thermal Engineering 26 (1 August 2021): 101091, https://doi.org/10.1016/j.csite.2021.10109)

2.2.2 United States

The United States ranks second in annual carbon emission and accordingly attracts researchers' attention towards the probable decline in carbon emission/concentration during the period of Government imposed shut down to prevent the pandemic from spreading. Carbon emissions from different sectors such as commercial, transport, industrial, residential and, electric power sector during the outbreak of COVID-19 had been reported by Aloal et al.[31]. The study revealed that carbon emission was reduced in most of the sectors during the lockdown.

The consistently declining trend of CO concentration was reported from 28 long-term air quality stations across the U.S. from March 15 to April 25, 2020, by Chen et al.[32]. Elshorbany et al.[33] used the remote sensing method to evaluate the concentration of CO in New York, Illinois, Florida, Texas, and California. Their study concluded that CO concentration reduced in most of the places. They also reported that in the presence of other sources of carbon emission excluding vehicles, the trend of reduction in carbon concentration may vary from place to place. Hudda et al.[34] studied the concentration of BC from vehicles in an urban area of the USA where vehicles are the main source of air pollution (Fig 4). They carried out the study in a mixed commercial-residential neighbourhood in Somerville between March 27 and May 14, 2020. The study revealed that BC concentration was reduced by 22-46% based on the type of roads.

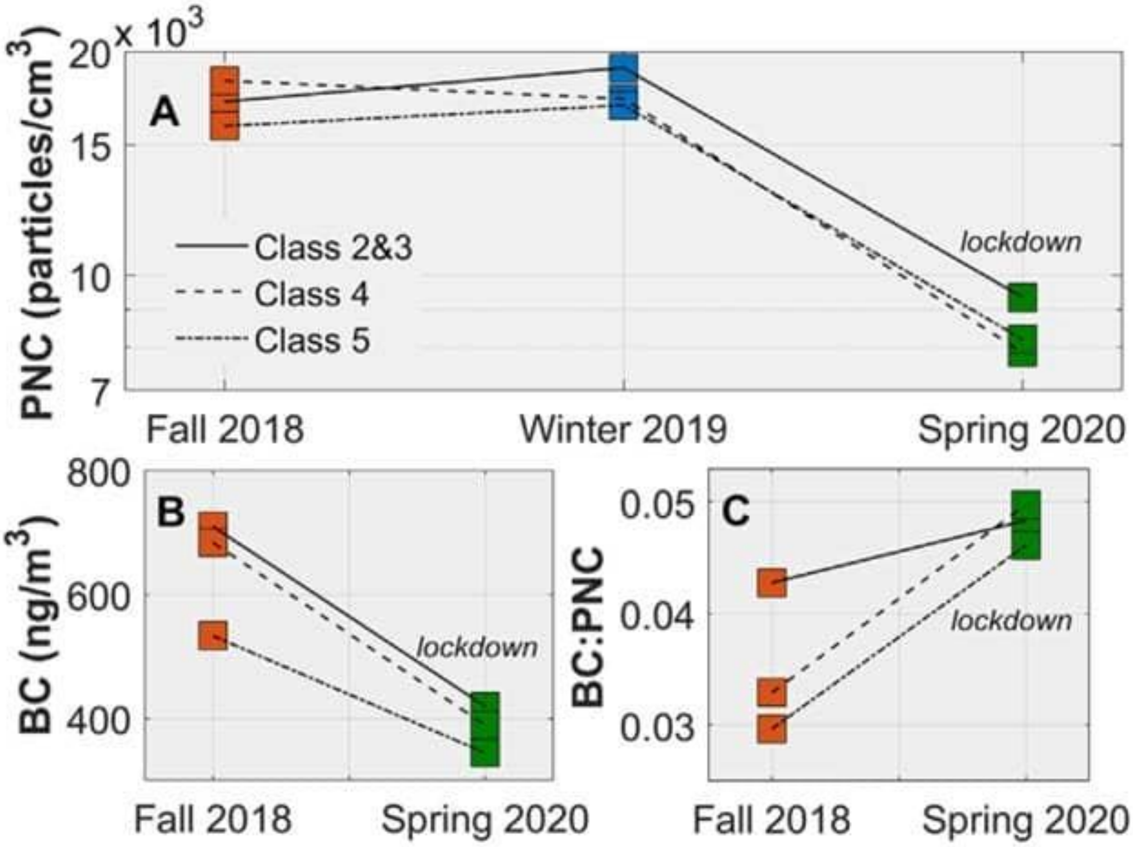

Fig 4. Seasonal medians for (A) PNC, (B) BC, and (C) concentration ratios (BC [ng/m3]:PNC[particles/cm3]) for different roadway classes in the study area. Each colored square represents the seasonal median of the median value of all measurements during a single lap of the monitoring route for each roadway class. (Reproduced with permission from Neelakshi Hudda et al., 'Reductions in Traffic-Related Black Carbon and Ultrafine Particle Number Concentrations in an Urban Neighborhood during the COVID-19 Pandemic', Science of The Total Environment 742 (10 November 2020): 19, https://doi.org/10.1016/j.scitotenv.2020.140931)

2.2.3 India

India is the second-highest populated country in the world. Being a developing country, the nation has a major emerging economy, the impact of which led to a concerning increase in annual carbon emission and thereby contributing to the climate crisis. Several studies have been reported in recent days to account for the effect of COVID-19 related shutdown on the variability of greenhouse gases, particularly, on carbon emission/concentration.

Along with the pan-India-based investigation on the effect of lockdown on carbon emission, several local/city-based studies are also reported. Ambade et al.[35] had followed such a study at Jamshedpur city, India before (January 3rd to March 23rd, 2020) and after lockdown (April 1st to June 14th, 2020) monitoring the reduction in BC during the lockdown. Their result depicted nearly 80% reductions in BC emissions because of diminished fuel consumption and a sufficient decrease in other emission sources. In another study by the same group[36], it was revealed that the BC concentration started to rise again as the restrictions were withdrawn during the unlock phases. Ajay et al.[37] studied BC emission from 2015 to May 2020 at a rural location Challakere, located 230 km northwest of Bengaluru, India. They found that the lockdown has a very marginal impact on BC emission at Challakere because the anthropogenic emission from vehicles or industry is very minimal at such a remote site. The same group[38] also studied the trends in carbon emissions in the megacity of Bengaluru, India during the span from 01 January to 25 May 2020. The results depicted a 60% reduction in BC emission due to lockdown. The two studies performed by this group indicated that the reduction in carbon emission is more significant in the urban/city area where anthropogenic emissions are mostly related to the transportation and industry sectors.

The BC concentration over Delhi, India from 18th February to 31st July, 2020 (Fig 5) was monitored by Goel et al.[39]. Their measurements unfolded a constant reduction in BC concentration during Government adopted restriction phases with a maximum recorded reduction of 78%. Sharma et al.[40] examined the result of lockdown caused by the COVID-19 pandemic in India on air quality in 22 cities from March 16th to April 14th pertaining to the years 2017 to 2020. The authors reported a 10% overall decrease in CO concentration as a consequence of lockdown. Prakash et al.[41] used satellite-based data to study the environmental impact of pandemic led lockdown in Delhi, Mumbai, Bengaluru, Chennai, and Kolkata, for March and April in 2019 and 2020. The general trend showed that CO concentration decreased during lockdown however, due to the presence of anthropogenic sources other than vehicles and factories, they also observed some spatio-temporal variations.

Among different sectors, the transportation sector was most badly affected due to the restrictions of lockdown. Gupta et al.[42] studied the lockdown effect on the air quality in India and reported that CO levels have been reduced to 10 ppm. BC concentration over the entire land area of India was measured by Gogoi et al.[43] using the Aerosol Radiative Forcing over India NETwork (ARFINET). The measuring stations are spread all over India and belong to different altitudes. They found that during the lockdown period the BC concentration reduced significantly across entire India. Moreover, the reduction rate is much higher at urban locations (40%) than at rural and remote locations (10%). Eregowda et al.[44] conducted a study to analyze carbon concentration from vehicle movement before and during the lockdown in four major IT hubs of India, namely, Bengaluru, Chennai, Hyderabad, and Pune. The results showed that there is a sharp drop in CO concentration by 27.6, 13.4, 9.8, and 37.1% in Bengaluru, Chennai, Hyderabad, and Pune, respectively, as most of the IT companies opted for a work-from-home culture during the lockdown. Both surface and satellite-based observations are utilized by Sathe et al.[45] to examine the carbon concentration pattern over India from 1st January to 17th May of the years 2017-2020. They used national, regional, and local level data to enhance the accuracy of the observations. Their findings revealed that the CO concentration, reduced all over India by 16-46 %. Bera et al.[46] measured the impact of COVID-19 lockdown on the CO concentration at megacity Kolkata, India from 25th March to 15th May 2020, and compared it to 3 previous years (2017-2019). Their study exhibited a significant reduction in CO concentration during the lockdown period with a maximum decrease (-6.88%) in May 2020.

The studies reported from different corners of the nation are quite substantial and also meticulous in exploring the distinct trends of carbon emission/concentration in different regions of India characterized by dissimilar anthropogenic resources. Such scientific reports are crucial for the practical implementation of climatic pollution-control schemes with moderate flexibility based upon the location of execution.

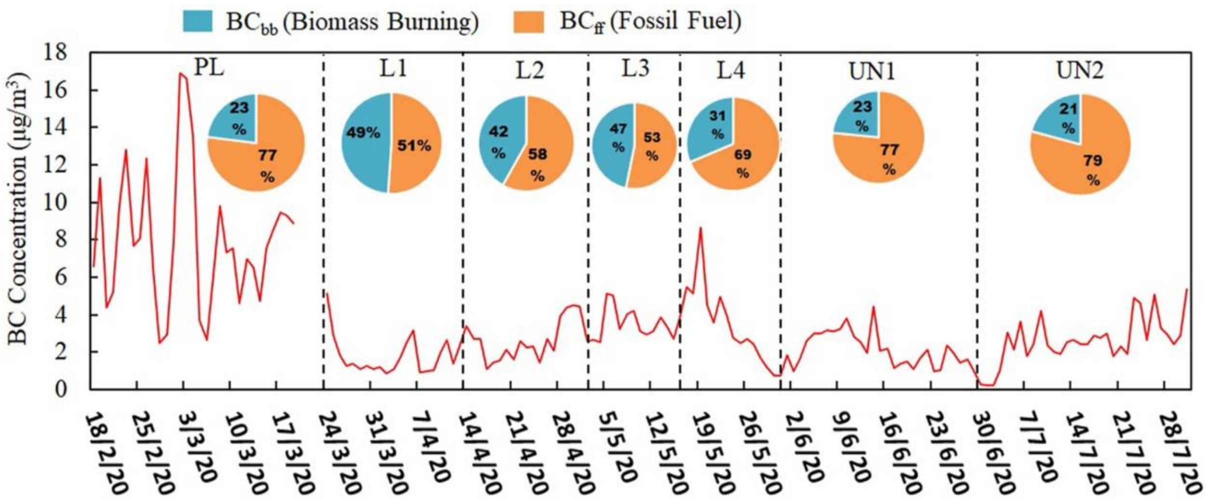

Fig 5. Temporal variation of BC mass concentration. (Reproduced with permission from Vikas Goel et al., 'Variations in Black Carbon Concentration and Sources during COVID-19 Lockdown in Delhi', Chemosphere 270 (1 May 2021): 129435, https://doi.org/10.1016/j.chemosphere.2020.129435.)

2.2.4 Other Countries

There are some reports from other countries regarding the studies related to carbon emission/concentration during the COVID-19 pandemic and their subsequent effects. Venturi et al.[47] measures the effect of the outbreak of COVID-19 on the level of CO_2 in the urban region of Italy named Florence. Using the eddy covariance technique they measured atmospheric CO_2 concentrations before, during, and after the national lockdown period. A detailed analysis of the obtained data exhibited that CO_2 concentrations decreased 62% during the lockdown phase while enhancement of the same was observed with the resumption of traffic. Numerous environmental aspects were studied by Ali et al.[48] across Pakistan and measured their change during the COVID-19 pandemic using satellite data. They compared the concentration of atmospheric CO during the lockdown in 2020 with the same period in 2019 and found that atmospheric CO concentration significantly decreased over all the megacities. Kanniah et al.[49] studied the effect of COVID-19 at several stations across Malaysia on different atmospheric parameters including CO concentration. They found that in the urban and suburban regions the reduction in CO concentration is much higher than in rural sites. The effect of COVID-19 lockdown on the air pollution level in Korea was examined by Ju et al.[50] and found that the concentration of CO was decreased by 17.33% due to a reduction in domestic sources.

3. Carbon Emission/Concentration over the Sea

There exist very few studies conducted over the sea region regarding the effect of COVID-19 outbreak-stimulated lockdown phases on carbon emission/concentration. Grados et al.[51] illustrated such an estimation of carbon emission over the sea region of Spain (Strait of Gibraltar) during the COVID-19 pandemic situation. Their study revealed that CO_2 emission decreased by a minimum of 10% in comparison to the previous records. However, Al Shehhi et al.[52]reported the effect of COVID-19 in the sea region globally. Their data evidenced a reduction of 7% in CO_2 emissions. Despite the scarcity of over-the-sea observations reported during the imposed restrictions of the COVID-19 pandemic, the fact-findings are ample enough to discernibly portray the distinguishable characteristics of carbon emission over land and sea.

4. Summary and Future Outlook

The COVID-19 pandemic around the world threatened the social pace of human life, unlike ever before. Moreover, the viral outbreak compelled mankind to encounter unprecedented situations like the complete shutdown of all kinds of social activities at different corners of the earth. The adopted restrictions to break the chain of transmission of the disease stirred up the escalating fear of livelihood loss and economic downturn due to the sudden and repeated approaches of close-down of all sorts of transportation as well as industry sectors in the strictest means. Despite the darkest impacts of the pandemic, such systematic curtailment turned out to be a blessing to the environment by causing a rapid dip in the ever-increasing trend of carbon emission/concentration. Several studies were conducted across the globe on carbon emission/concentration during the lockdown period to estimate the effect of lockdown (Table 1).

Table 1: Summary of carbon emission/concentration-related studies during the COVID-19 pandemic.

Sl No	**Measured Parameter (BC/CO/ CO_2)**	**Facility used primarily (for measurement/as data source)**	**Duration of measurement**	**Place/Area/Region of measurement**	**Change in emission**	**Change in concen-tration**	**Ref No**
1	CO_2	Carbon Monitor (https://carbonmonitor.org)	1st January 2019 to 30th June2020	Global	-8.8% (−1551 Mt)		[10]
2	CO_2	Carbon Monitor (https://carbonmonitor.org)	1st January 2019 to 30th April 2020	Global	–17%		[12]
3	CO_2	International Energy Agency(https://www.iea.org) and Carbon Monitor (https://carbonmonitor.org)	January to April (2019 - 2020)	Global	-14% (-1749 Mt)		[13]
4	CO_2	International Energy Agency (https://www.iea.org) and bp (https://www.bp.com) and Ember (https://ember-climate.org)	January to September (2019 - 2020)	Global	-6.8%		[14]

5	BC	17 European stations (https://www.actris.eu) and accent-network (http://www.accent-network.org) and Nasa (https://disc.gsfc.nasa.gov)	2015 to 31st April 2020	Global	-11%(-23 kt)		[15]
6	CO_2	NBS , China (http://www.stats.gov.cn/english/)and https://oil.chem99.com	01st September 2018 to 31st August 2020	China	−46.45 %		[18]
7	CO_2	Carbon Monitor (https://carbonmonitor.org)	January to May (2019 - 2020)	China	- 6.9%		[19]
8	CO_2	Carbonbrief (https://www.carbonbrief.org) and NBS , China (http://www.stats.gov.cn/english/)	January to April (2019 - 2020)	China	-18.7%		[20]
9	CO_2	NBS, China (http://www.stats.gov.cn/english/) and Wind (https://www.wind.com.cn/en/edb.html)	January to April (2019 - 2020)	China	-11.0% (-257.7 Mt)		[21]
10	CO and BC	NBS , China (http://www.stats.gov.cn/english/) and Tomtom (https://www.tomtom.com/en gb/traffic-index/) and Copernicus	01st January 2019 to 31st Decemb	China	-5% (CO) -4%(BC)		[22]

		(https://cds.climate.copernicus.eu/cdsapp#!/home)	er 2020				
11	CO_2	Tropomi (http://www.tropomi.eu) and NBS, China (http://www.stats.gov.cn/english/) and European Centre for Medium-Range Weather Forecasts (https://www.ecmwf.int) and Sedac, NASA (https://sedac.ciesin.columbia.edu)	January to April (2019 - 2020)	China	-11.5%		[23]
12	CO_2	Nondisper- sive Infrared Spectroscopic analyzer (NDIR) and Cavity Ring-Down Spectroscopic analyzer (CRDS)	01st January 1993 to 31st March 2020	China	-(32 ± 12%)		[24]
13	CO	Tropomi (http://www.tropomi.eu) and NOAA (https://www.ospo.noaa.gov/Products/atmosphere/soundings/iasi/) and Copernicus (https://scihub.copernicus.eu) and Aeris (https://iasi.aeris-data.fr/cos_iasi_b_arch/) and Firms, NASA (https://firms.modaps.eosdis.nasa.gov)	January to May (2019 - 2020)	China		-18.7%	[25]

14	CO	China National Environmental Monitoring Centre (http://www.cnemc.cn/en/) and National Meteorological Information Centre (https://data.cma.cn/en)	23rd January to 22nd April (2019 - 2020)	China		-30%	[26]
15	CO	http://www.tianqihoubao.com/lishi/	January to March (2017–2020)	Wuhan, Jingmen, and Enshi (China)		-27.9%	[27]
16	BC	Multiwavelength Aethalometer	01st January to 31st March 2020	Hangzhou, China		-44% (-1.1 μg/m^3)	[28]
17	CO	Shanghai Municipal Bureau of Ecological Environment (https://sthj.sh.gov.cn)	25th November 2019 to 22nd May 2020	Shanghai Municipality, China		Declination in CO concentration	[29]
18	CO	Gas Filter Correlation CO Analyzer	January to March 2020	Hangzhou, China		-30%	[30]
19	CO	AirNow (https://www.airnowtech.org) and EPA (https://www.epa.gov/outdoor-air-quality-data)	January to April (2017-2020)	USA		Declination in CO concentration	[32]

20	CO	Terra, NASA (https://terra.nasa.gov/data/mopitt-data) and Highway Performance Monitoring System (https://www.fhwa.dot.gov/policyinformation/hpms/hpmsprimer.cfm) and NASA (https://earthdata.nasa.gov/eosdis/daacs/asdc)	March to May (2015-2019)	USA		Declination in CO concentration	[33]
21	BC	Tufts Air Pollution Monitoring Lab and Airnow (https://docs.airnowapi.org)	27th March to14th May, 2020	Somerville (USA)		-(22-46%)	[34]
22	BC	Aethalometer and https://www.worldweatheronline.com	3rd January to 23rd, March and 1st April to 14th June 2020	Jamshedpur, India	- 80%		[35]
23	BC	Aethalometer	01st January to 25th May 2020	Bengaluru, India	-60%		[38]
24	BC	Aethalometer	18th February to	Delhi, India		-78%	[39]

			31st July, 2020				
25	BC	ARFINET (https://arfinet.vssc.gov.in/arfinet/index.html)	25th March to 31st May, 2020	India		-(10-40%)	[43]
26	CO	MCD19A2 (https://lpdaac.usgs.gov/products/mcd19a2v006/) and Sentinel 5P (https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-5p) and EarthEngine (https://earthengine.google.com)	March and April (2019 - 2020)	India		Declination in CO concentration	[41]
27	CO	NASA (https://www.nasa.gov) and World's Air Pollution (https://waqi.info)	January to April (2019-2020)	India		Reduced to 10ppm	[42]
28	CO	CPCB (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing)	16th March to 14th April (2017-2020)	India		-10 %	[40]

29	CO	CPCB (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing) and World Population Review (https://worldpopulationreview.com)	1st March to 15th April (2019-2020)	India		Declination in CO concentration	[44]
30	CO	CPCB (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing) and NASA (https://earthobservatory.nasa.gov/images) and NOAA (https://www.ncei.noaa.gov/products/land-based-station/integrated-surface-database) and ESA (https://www.esa.int/Applications/Observing_the_Earth/Copernicus/)	1st January to 17th May (2017-2020)	India		16-46 %	[45]
31	CO	WBPCB (https://www.wbpcb.gov.in) and LANDSAT (https://www.usgs.gov/core-science-systems/nli/landsat/landsat-satellite-missions?qt-science_support_page_related_con=0#qt-science_support_page_related_con) and TROPOMI (http://www.tropomi.eu/data-products/mission-performance-	25th March to 15th May (2017-2020)	Kolkata, India		-6.88%	[46]

		centre)					
32	CO_2	A three-dimensional sonic anemometer and open-path infrared gas analyzer and cavity ring-down spectrometer	13th January to 4th June, 2020	Florence, Italy	-62%		[47]
33	CO	TROPOMI (http://www.tropomi.eu/data-products/level-2-products) and MODIS (https://lpdaac.usgs.gov/news/release-of-modis-version-6-maiac-data-products/) and Copernicus (https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1)	23rd March to 15th April (2019-2020)	Pakistan		Declination in CO concentration	[48]
34	CO	Himawari 8 (https://himawari8.nict.go.jp) and AERONET (https://aeronet.gsfc.nasa.gov) and Environment department, Malaysia (https://www.doe.gov.my/portalv1/en/)	18th March to 30th April (2018-2020)	Malaysia		-(25-31%)	[49]
35	CO	Korea Ministry of Environment (https://www.airkorea.or.kr/web)	1st December to 30th April	Korea		-17.33 %	[50]

			(2017-2020)				
36	CO_2	Six fast ferries	15th March to 15th June (2020)	sea region of Spain (Strait of Gibraltar)	-10%		[51]
37	CO_2	MODIS (https://modis.gsfc.nasa.gov/about/)	6th April to 15th Jun (2019-2020)	global ocean	-7%		[52]

The reports over the land and sea regions are reviewed and the findings depicted a clear picture of the steady decline of carbon emission/concentration around the world during the lockdown period. However, the extent of decrease is utterly different over land and sea. In contrast to the over-the-land reports, the rate of reduction is significantly lower over the sea due to the obvious reason of the limited provision of transportation through the sea and the carbon-absorbing phenomenon of the water bodies. Under these circumstances, the only possible source of carbon over the sea region can be the transported portion of it from the nearby land location. Moreover, the change in carbon emission/concentration is more significant in city/urban areas compared to the rural/remote region as both the vehicles and industries are dominant factors for the former one. It was also noticed that initially, the carbon emission/concentration was decreased with the immediate imposition of lockdown, but carbon emission/concentration gradually increases in the unlock phases as the people started to return to normal life. Thus the declining carbon emission/concentration during

COVID-19 extends only temporary relief. Though the carbon emission/concentration reduced because of some unprecedented situations, however, it can be inferred that some specific strategies (e.g. work from home, bicycle to work, etc.) can be adopted by the concerned authorities to achieve reduced carbon emission/concentration and provide breathable air to the world.

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